THE MIOCENE DIABASE OF THE SANTA CRUZ MOUNTAINS IN SAN MATEO COUNTY, CALIFORNIA.[1]

BY H. L. HAEHL AND RALPH ARNOLD.

(*Read February 5, 1904.*)

INTRODUCTION.[2]

The presence of the basic eruptives in the Santa Cruz Mountains of San Mateo County, California, and portions of Santa Clara and Santa Cruz Counties, was first noted in 1865 by J. D. Whitney. In discussing the geology in the vicinity of Searsville, Whitney says:[3]

"In the bed of the creek (one mile west of the ridge in which the coal mine is situated) were, among the boulders of sandstone, some fragments of syenitic granite and of a basaltic rock, which latter is said to cap a few of the highest points of this ridge." Whitney's party also passed over the divide from San Mateo to Halfmoon Bay, noting the Cretaceous and Miocene strata and the Montara granite exposed along the road, but seem to have overlooked the diabase exposures on the east and south of the granite outcrop.

W. L. Watts in a paper[4] on San Mateo County says: "At some points basaltic rocks have been observed, and on the San Gregorio Rancho the Field Assistant of the Bureau noted and obtained specimens of vesicular dolerite, the vesicles of which were filled with petroleum."

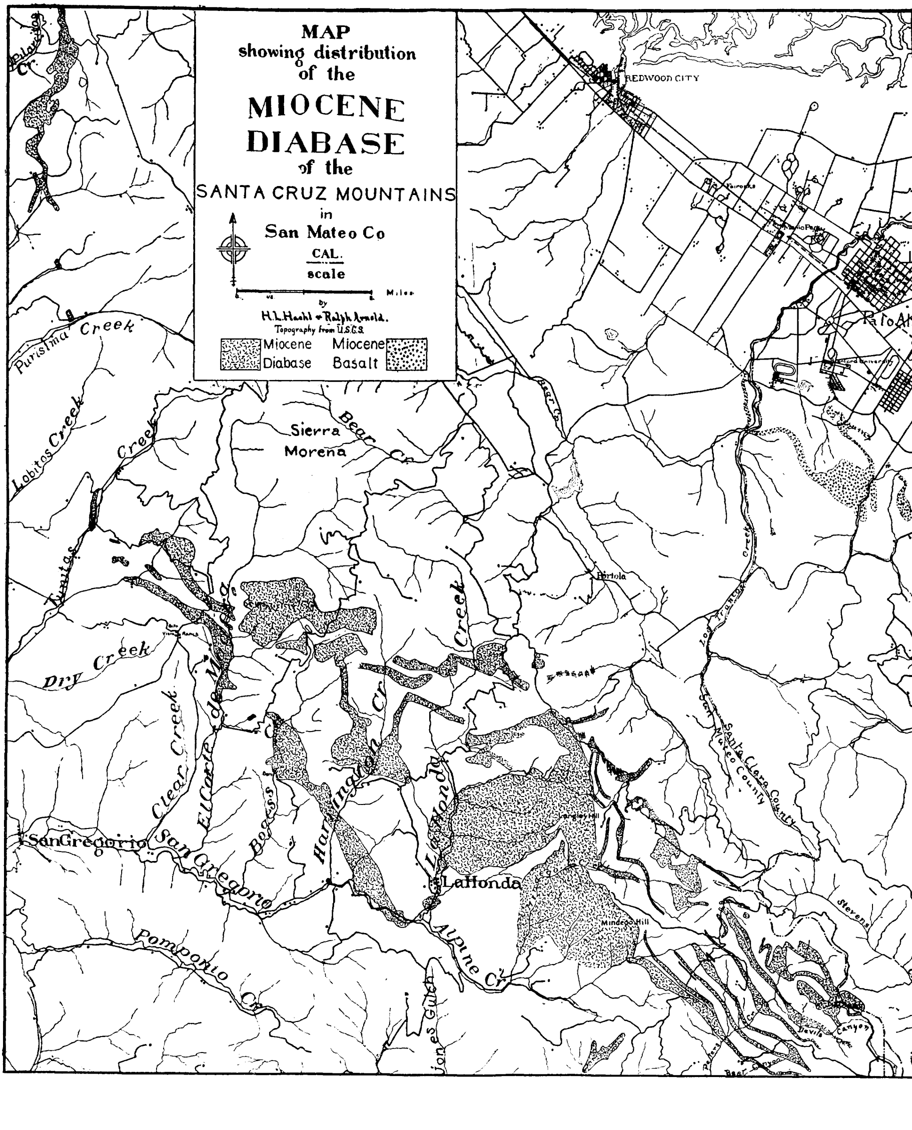
[1] Published by permission of the Director of the U. S. Geological Survey.

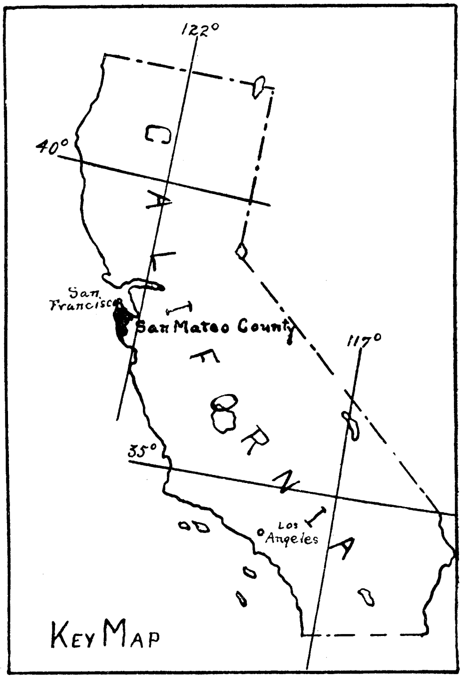
[2] The work of which the results are given in this paper was done while the authors were post-graduate students of geology in Stanford University, under the direction of Dr. J. C. Branner. The authors wish to acknowledge their indebtedness to Dr. Branner for suggestions regarding the field relations, especially of the tuffs and associated rocks, and to Dr. J. P. Smith for suggestions relating to the petrographical work.

The names used in the lists of fossils in this paper are those commonly applied to the respective species by the West Coast paleontologists. Owing to the imperfect state of our knowledge regarding the nomenclature of the California Tertiary fauna, there is a probability that some of the names used are erroneous: the writers, therefore, reserve the privilege of revising any or all of the names if future study shall warrant it.

[3] *Geological Survey of California*, Vol. I, p. 71, 1865.

[4] *Tenth Ann. Rept. Calif. State Mineralogist*, p. 586, 1890.


MAP
showing distribution
of the
MIOCENE
DIABASE
of the
SANTA CRUZ MOUNTAINS
in
San Mateo Co
CAL.
scale
Miles
by
H. L. Haehl & Ralph Arnold.
Topography from U.S.G.S.
Miocene Diabase
Miocene Basalt
REDWOOD CITY
Palo Alto
Purisima Creek
Lobitos Creek
Creek
Tunitas
Sierra Morena
Bear Cr.
Bear Cr.
Dry Creek
Clear Creek
El Corte de Madera
Harrington Cr.
La Honda
Creek
Portola
Los Trancos
Creek
San Mateo County
Santa Clara County
San Gregorio
San Gregorio
Bogess
La Honda
Alpine Cr.
Pomponio Cr.
Jones Gulch
Mindego Hill
Langley Hill
Devils Canyon
Stevens
Cr.



FIELD RELATIONS.

General Relations of the Diabase.

The exposures of the diabase have been traced for a distance of approximately thirty-two miles in a generally southeasterly direction from a point near the San Mateo-Halfmoon Bay road, on Pilarcitos Creek, in San Mateo County, to a point on the headwaters of Lompico Creek, four miles east of the town of Boulder Creek, in Santa Cruz County. There is also a basaltic outflow exposed near Stanford University, which is probably closely related genetically to the diabase. The exposures east and south of those found at the head of Devil's Canyon are not shown on the map, as, with one exception, they are of minor importance. The largest exposed areas of the diabase are in the vicinity of Langley and Mindego Hills east of La Honda, and on the ridges between the headwaters of Pescadero Creek and the San Lorenzo River (the latter being outside of the area shown on the accompanying map).

The whole area presents at the surface a chain of more or less connected patches of diabase, extending approximately parallel to the coast, and also parallel to, but southwest of, the major axis of the Santa Cruz Mountains. The continuity of the patches is hidden by overlying strata and by dislocated masses of country rock and soil to such an extent that the exact relations of the various facies are difficult to ascertain.

It is possible, however, to determine the age of the igneous mass by its relation to the sediments about it. The relations of the stratified rocks of the area under discussion are as follows: [1]

Pliocene	Purisima formation with *Astrodapsis* n. sp., *Lucina acutilineata*, *Nucula castrensis*, *Pecten* 3 n. sp., A, B, and C, *Rostellaria undulata* and *Saxidomus gibbosus*.
Miocene	Monterey shale with *Arca montereyana*, *Callista angustifrons*, *Pecten peckhami*, and *Tellina congesta*. Vaquero sandstone with *Agasoma barkerianum*, *A. kernianum*, *Pecten magnolia*, and *Turritella hoffmani*.

Associated Sedimentary Formations.

The diabase proper breaks through beds of lower, and perhaps middle, Miocene age; while the associated diabase tuff is interbedded with strata containing a typical lower Miocene fauna and lies below the Monterey shale. The basalt [2] outflow exposed near Stanford University overlies and metamorphoses beds of lower Miocene age, and is overlain by beds containing a fauna very similar to the underlying strata. This evidence indicates the lower Miocene age of the basalt and its probable contemporaneousness with the diabase tuffs of Mindego and Langley Hills. Both the intrusive diabase and the tuff are in many places overlain by the Purisima (lower Pliocene) beds, which show a distinct erosion line at their base, and also often a basal conglomerate made up of diabase pebbles.

[1] An uplifted mass of impure stratified limestone, containing a fauna that indicates its probable lower Eocene age, occurs in the diabase area between the headwaters of Pescadero Creek and the San Lorenzo River. This limestone appears to have no visible stratigraphic relations with the Miocene shales surrounding the diabase.

[2] This basalt is the subject of a paper now in course of preparation by Prof. Milnor Roberts, of the University of Washington.

MIOCENE.—(1) *The Vaquero Sandstone.* The lower Miocene of the area consists of a series two or three thousand feet thick of massive, coarse, yellowish sandstone layers, interbedded with a few layers of varying thickness of dark-colored argillaceous shale, the whole overlain by three or four hundred feet of thin-bedded siliceous shales. The lower part of this series of beds, including most of the sandstone, appears to have the same fauna and occupy the same stratigraphic position as the Vaquero sandstone of the Salinas Valley.[1] The name "Vaquero" will, therefore, be used to designate the lower Miocene sandstone in the area under discussion. The sandstone and shale series is typically developed in the region between the headwaters of Stevens Creek and the lower portion of Peters Creek. Fig. 1 shows a typical section of this area.

The fauna of the Vaquero sandstone series indicates its lower Miocene age. The following fossils, most of which are characteristic of the lower Miocene, are among others found in the Vaquero sandstone on Mindego Creek, Langley Creek, at the head of Stevens Creek, and at other points in the area under discussion:

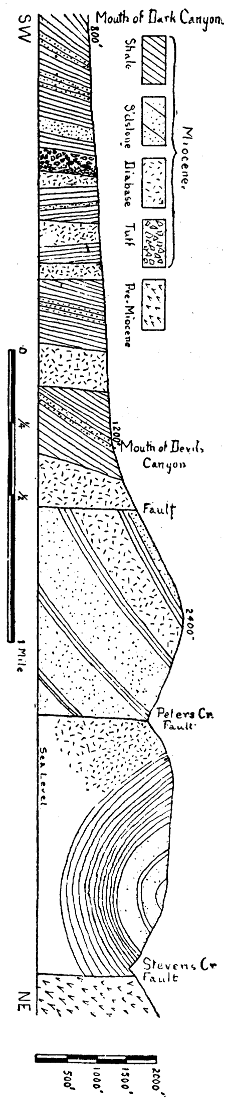


Fig. 1. Southwest-northeast section up Peters Creek and over main ridge into Stevens Creek, showing relations of diabase to Miocene and older formations.

[1] The name for this sandstone was suggested by Mr. Homer Hamlin, and was first used by Dr. Fairbanks in the San Luis folio. This sandstone is typically developed in the Los Vaqueros Valley, near the Salinas Valley, Monterey County.

List of Vaquero (Lower Miocene) Fossils.—Those marked with a (*) are characteristic, so far as known.—

- **Agasoma barkerianum* Cooper
- **Agasoma gravida* Gabb
- **Agasoma kernianum* Cooper
- **Arca microdonta* Conrad
- *Balanus estrellanus* Conrad
- **Cardium* (*Trachycardium*) n. sp. A.
- **Chione mathewsonii* Gabb
- *Chione* n. sp. A. (very large)
- **Conus* n. sp. A.
- *Crepidula grandis* Midd.
- **Cuma biplicata* Gabb
- **Dosinia conradi* Gabb
- *Dosinia mathewsonii* Gabb
- **Dosinia* cf. *montana* Conrad
- *Dosinia* aff. *ponderosa* Gray
- **Galeocerdo productus* Agassiz
- *Galerus* cf. *excentricus* Gabb
- **Glycymeris* n. sp. A. (very large)
- **Lamna clavata* Agassiz
- *Lucina acutilineata* Conrad
- *Lucina richthofeni* Gabb
- *Mytilus mathewsonii* Gabb
- *Neverita recluziana* Petit
- *Ostrea titan* Conrad
- *Panopea generosa* Gould
- *Pecten estrellanus* Conrad
- **Pecten* (*Chlamys*) n. sp. E.
- **Pecten* (*Lyropecten*) *magnoliæ* Conrad
- *Pecten* (*Plagioctenium*) n. sp. E.
- **Periploma* n. sp. A.
- *Psammobia edentula* Gabb
- **Pyrula* (?) sp. A.
- **Pinna alamedensis* Yates
- **Sigaretus scopulosus* Conrad
- *Solen sicarius* Gould
- **Tivela ineziana* Conrad
- **Trochita costellata* Conrad
- **Turritella hoffmani* Gabb
- **Turritella ocoyana* Conrad
- **Yoldia* n. sp. aff. *cooperi* Gabb

(2) *The Monterey Shale.* The shales overlying the coarse yellow Vaquero sandstone are in some places thin-bedded, soft and chalky, while in others they are hard, dark colored and somewhat more massive. The white facies of the shale is found overlying the diabase tuff in the region just west of the Langley Hill-Mindego Hill igneous area, while the dark colored facies is found on the northeast slope of the main ridge between the summit and Corte de Madera Creek. These shales represent at least a part of the Monterey series, which is supposed to be of middle Miocene age. The upper part of the Vaquero sandstone series, at least that part showing alternating beds of sandstone and shale with a tendency to grade from the sandstone vertically upward into the shale, may be the inshore equivalent of some of the Monterey shale found at the typical locality in the region around Monterey. This

theory is supported by the fact that, where typically developed, the Monterey shale is between twenty-five hundred and three thousand feet thick and rests on a comparatively thin layer of sandstone, while, in the area under discussion, the relative proportions of shale and sandstone are exactly the reverse. The harder, more flinty shales which appear along the coast are not found in the vicinity of the diabase.

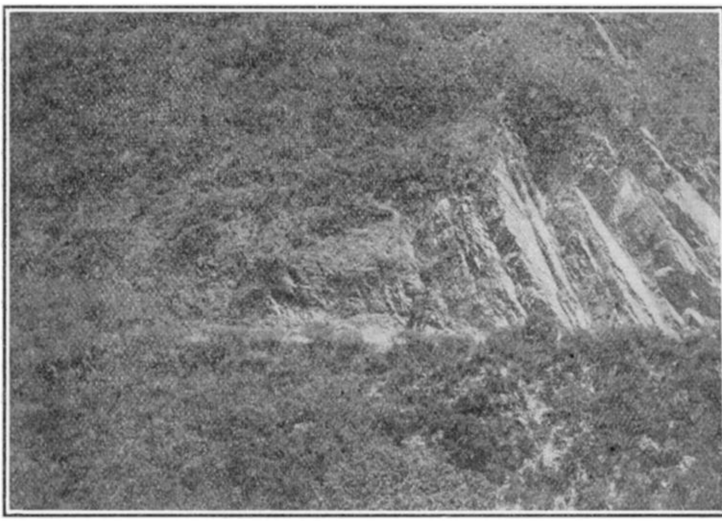


Fig. 2. View on the Searsville-La Honda road three-fourths mile south of summit, looking east, showing the Miocene shale beds resting against the diabase which has intruded them in sill-like dikes. The man points at the contact. Photograph by Ralph Arnold.

The following species of fossils have been found in the Monterey shale within the diabase area:

List of Fossils from the Monterey Shale (Miocene).—Those marked (*) are characteristic, so far as known.—

**Arca montereyana* Osmont
Callista angustifrons Conrad
Chione mathewsonii Gabb
* *Corbula* sp. A.
Cylichna cf. *petrosa* Conrad
Cythera cf. *vespertina* Conrad
**Diplodonta* n. sp. aff. *serricata* Reeve
**Leda* sp. A. and B.
Pecten peckhami Gabb
Pecten (*Plagioctenium*) n. sp. E.
**Semele* n. sp. A.
Siliqua sp. A.
* *Tellina congesta* Conrad

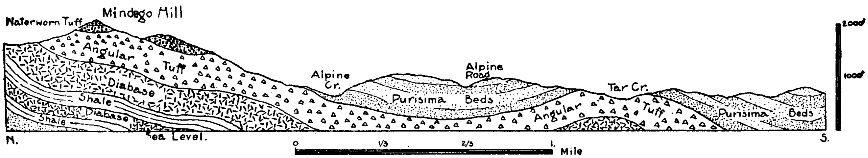


Fig. 3. North-south section from Mindego Hill to Tar Creek, showing the relation of the diabase tuffs to the overlying Purisima beds.

PLIOCENE.—*The Purisima Formation.* Within the area under discussion is an extensive series of conglomerates, fine-grained sandstones and shales for which the writers propose the name "Purisima formation."[1] This name has been chosen because of the typical development of the formation in the vicinity of Purisima Creek, San Mateo County. The Purisima beds lie unconformably upon the Vaquero sandstone and Monterey shale, and at the top grade into beds having a fauna somewhat similar to that of the Merced formation. Its upper limit may be defined as the base of the Merced. In age the Purisima probably represents the lower, and perhaps middle, Pliocene. The individuality of the fauna, stratigraphy and lithology of this formation appears to warrant the application of a new and distinctive name. Fig. 4 shows a typical section of the Purisima formation in the area.

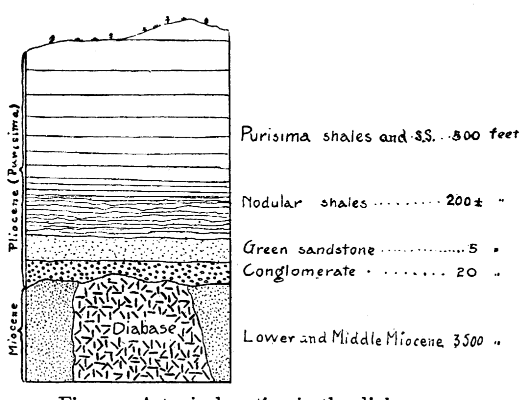


Fig. 4. A typical section in the diabase area.

Stratigraphically the Purisima formation presents a uniform cross

[1] The junior author now has in course of preparation a paper giving in detail the characteristics and faunal relations of this formation.

section throughout nearly the whole diabase area. At its base is the conglomerate, consisting of water-worn diabase pebbles cemented by a more or less siliceous sand. In some places, however, the amount of diabase is so great that it is difficult to distinguish the beds, where badly weathered, from the diabase tuff.

The presence of barnacles (*Balanus*) and of a single specimen of *Pecten* afford the best evidence of the sedimentary nature of the deposit, and fix its origin as marine. The conglomerate is not always of this nature, however. South of the Alpine schoolhouse the base of the Purisima consists of a rather incoherent shale breccia, which had its origin in a talus slope. Part of a *Balanus* was found in this breccia, showing that at least part of the deposit was laid down under water. In places fragments of the Miocene shale, together with hardened sandstone and chert, make up the greater portion of the basal layers, indicating possibly that the Purisima coast line lapped over the intruded area and obtained its materials, not from the diabase area, but from beds to the east of them. The total thickness of the Purisima formation is probably about seven hundred feet. As a rule the conglomerate beds are thin; the thickest of them are about twenty feet in thickness. At some localities, notably at a place a quarter of a mile southwest of the Alpine schoolhouse, the base of the Purisima consists of shale, which rests unconformably upon the diabase.

Above the conglomerate is a thin bed (four or five feet) of soft green sandstone, stained by the chloritic weathering products of the diabase. It contains bones and sharks' teeth and, in some localities, a rich marine invertebrate fauna. Over the green sandstone is a bed of an unfossiliferous, nodular shale of perhaps two hundred feet in thickness.

On the top of the unfossiliferous shale are sandy shales and fine sandstones probably five or six hundred feet thick. While these may readily be distinguished by their lithology, they are also characterized by numerous fossils which are in a fair state of preservation. The following species were gathered from the Purisima beds in different parts of the area under discussion:

List of Fossils from the Purisima (Pliocene) Formation.—Those marked with a (*) are characteristic, so far as known.—

***Arca canalis* Conrad
Arca trilineata Conrad
**Astrodapsis* n. sp. Merriam
Astyris richthofeni Gabb
Balanus estrellanus Conrad
**Buccinum* n. sp. A.
**Calliostoma* n. sp. A.
Callista angustifrons Conrad
**Cancellaria* n. sp. A.
Cardium meekianum Gabb
**Cardium meekianum* n. var. A.
Chrysodomus liratus Martyn
Chrysodomus tabulatus Baird
**Chrysodomus* n. sp. aff. *tabulatus*
Crepidula grandis Midd.
Crepidula rugosa Nuttall
**Cryptomya* n. sp. aff. *californica*
**Dolichotoma* n. sp. aff. *carpenteriana*
Drillia incisa Carpenter
Galerus mammillaris Broderip
Glottidia albida Hinds
**Lævicardium* n. sp. aff. *substriatum*
Leda cf. *fossa* Baird
Leda taphria Dall
Lucina acutilineata Conrad
Lunatia lewisii Gould
Macoma inquinata Deshayes
Macoma nasuta Conrad
Mactra californica Conrad
Mactra falcata Gould
Modiolus rectus Conrad
Mytilus mathewsonii Gabb
Nassa californiana Conrad
**Neptunea humerosa* Gabb
Nucula castrensis Hinds
Olivella intorta Carpenter
Olivella pedroana Conrad
Panomya ampla Dall
Panopea generosa Gould
Pecten expansus Dall
Pecten hastatus Sby. (smooth var.)
**Pecten* n. sp. aff. *expansus*
**Pecten* n. sp. aff. *dilleri* Dall
**Pecten* n. sp. aff. *parmeleei*
**Priene oregonensis* Redfield (n. var. ?)
Purpura crispata Chemnitz
Rostellaria indurata Conrad
Saxidomus gibbosus Gabb
Scutella interlineata Stimpson
Siliqua patula Dixon
Solariella peramabilis Carpenter
Tapes staleyi Gabb
Tapes tenerrima Carpenter
Tellina aff. *congesta* Conrad
Tresus nuttalli Conrad
**Voluta* n. sp.

Relation of the Diabase to the Associated Sedimentaries.

The masses of diabase follow the bedding, particularly in the shale of the lower Miocene series, and it is in between shale beds that most of the diabase exposures occur. Fig. 2 shows some shale beds resting against a large diabase dike which crosses the Searsville-La Honda road near the summit of the Santa Cruz range. The diabase dike in this case was intruded between and followed

the bedding planes of the shale in the form of a sheet. There are some very striking exceptions to the sheet-like occurrences of the diabase, but in general the ready cleavage of the shale along the bedding planes seems to have offered the line of weakness which the intrusive rock followed. Fig. 5 shows a characteristic case of the diabase breaking through the Miocene shales and sandstones. The shale in the middle of the dike in this exposure is slightly darker colored and somewhat harder than the shale beneath the diabase. The sandstone was not affected by the intrusive rock.

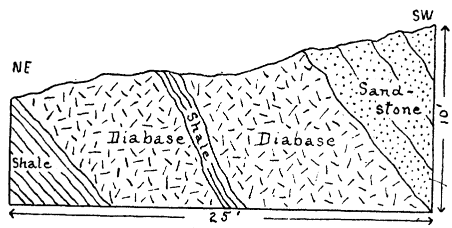


Fig. 5. Vertical section exposed in small ravine on Dornberger's ranch, near the Page Mill road summit, showing diabase intrusive in shale and between shale and sandstone.

Inclusions of sandstone and shale are plentiful and vary from the size of a walnut to masses of hundreds of tons, but no evidence of the alteration of the sandstone has been noted, except in the case of the underlying beds of the basalt near Stanford University. Some well-preserved vertebrate bones and teeth (*Oxyrhina tumula* Agassiz) were found in a sandstone inclusion two feet in diameter about one-half mile north of the Alpine schoolhouse. Fig. 6 shows an inclusion of light yellow sandstone found near the edge of a large diabase dike on the Searsville-La Honda road. Neither the intruded sandstone, which is seen in the upper right-hand corner of the picture, nor the inclusion is in the least altered.

The inclusions of shale are usually somewhat metamorphosed, but the metamorphism is not radical, changes in color and texture being the chief phenomena. An inclusion of shale four inches thick metamorphosed to a hard, brittle flint was found in the diabase on Oil Creek. Similar occurrences were noted at several other localities in the area under discussion. Fig. 7 shows a shale layer which has been slightly hardened by an intrusion of diabase. This is an example of a somewhat common phenomenon.

Fig. 6. Inclusion of sandstone in diabase dike seen in vertical cut beside the Searsville-La Honda road three miles north of La Honda. Photograph by Ralph Arnold.

Fig. 7. View on the Page Mill road two hundred yards south of the summit, looking northeast, showing shale layer slightly hardened at the contact with the diabase dike. Photograph by Ralph Arnold.

An interesting section (shown in Fig. 8) is exposed beside an old road one-half mile north of the Langley ranch house. The diabase at that place breaks through the Miocene shales, following the bedding planes in a general way, but sometimes breaking through the beds. Small inclusions of the shale are found in the diabase, but no alteration of either the inclusions or beds thus intruded was noticed.

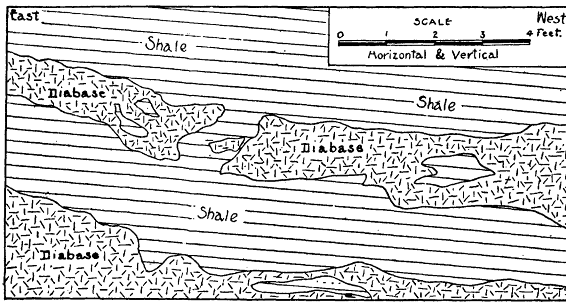


Fig. 8. Vertical section of bank on south side of road one-half mile north of Langley's ranch house, showing diabase intrusion in shale. The shale, which is unaltered, dips into the bank at an angle of 35°.

The Purisima beds (Pliocene) which cover large areas of the diabase are not penetrated by the diabase. This may explain the presence of only small, isolated patches of the diabase along the northern end of the area. Either the Miocene or post-Miocene denudation over the northern end of the diabase area must have been great, or else the Monterey shale must be represented by sandstone over that territory, for there, wherever the diabase is exposed, it is in the Vaquero sandstones, while the Monterey shale appears to be almost lacking. Over this tract a deposition of the Purisima sediments took place after the denudation and covered large areas of the eroded surface of the diabase. At the base of the Purisima beds are conglomerates made up largely of diabase pebbles, and these conglomerates are now exposed in the canyons together with small areas of the diabase in place. The presence of the diabase conglomerate at the base of the Purisima formation, together with the fact that the diabase is intrusive in the Miocene, establishes the time of at least the greater part of the igneous intrusions as later than the middle Miocene (Monterey), and before the Pliocene (Purisima). It is noticeable that the exposures of diabase in sev-

eral instances are low down on the south-facing slopes of the ridges next to the creek beds, but are not visible on the north-facing slopes. This seems to be more than a mere coincidence. The difference of exposure on the two sides of the canyon may be due partly to the thick vegetation and partly to the depth of decomposition and the admixture of organic matter in the formation of the soil on the north-facing slopes.

In general the Miocene shales near the diabase dip away from the intrusion as if it were the axis of an anticline. (See Fig. 2.) This may be due to a lifting action of the diabase upon nearly horizontal strata, or possibly to the fact that a pre-existing axis presented the line of weakness along which the intrusion was made. There are instances of sill-like intrusions or sheets between the sedimentary beds of this area. The evidence of oil well records is available in some instances to show the presence of such sheets. At well No. 1, on San Gregorio Creek near the mouth of Harrington Creek, the San Mateo Oil Company put down a test hole, and a sheet of diabase was encountered at a depth of one hundred feet. A hundred feet deeper the drill passed through the diabase and again entered the shale. This well is about a quarter of a mile from the igneous outcrop on Harrington Creek. Mr. Bell, on whose property another well was bored about ten years ago, is authority for the statement that no diabase was encountered in sinking that well, which is about four hundred yards west of San Mateo Oil Company's well No. 1, and away from the diabase.

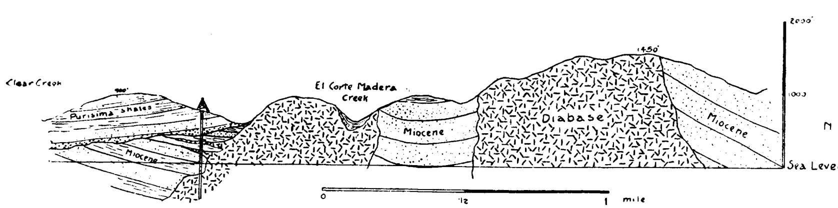


Fig. 9. Northeast-southwest section through the Bella Vista oil well, San Mateo County. Photograph by Ralph Arnold.

The well sunk by the Bella Vista Oil Company on the Bella Vista ranch, north of El Corte Madera Creek, encountered, according to the report of the driller, a fifty-foot stratum of diabase at a depth of four hundred and fifty feet; the drill then passed into shale for another hundred feet, after which it again passed through diabase

for fifty feet and again entered the shale. After passing through a few hundred feet of the shale the well entered the diabase again, and was still in the igneous rock when discontinued. Microscopic slides of the diabase encountered in this well showed it to be very similar to the exposure a quarter of a mile to the east, except that the rock was badly blackened with carbonaceous matter.

The Tuff.

The tuffs associated with the diabase are confined to the Langley Hill-Mindego Hill igneous area, of which they form the major portion. Within this area are also found diabase both of the diabasic and basaltic types, limestone beds, limestone dikes or intrusions, shale and sandstone. It is to be regretted that all of the rocks within this area cannot be differentiated on the map, as their areal distribution would throw much light on the structure of the territory within which they occur. Beds of sandstone containing a typical lower Miocene fauna (given on a previous page) are found between layers of the tuff, while the shales containing *Pecten peckhami*, when associated with the tuffs, are always found above them. This places most of the tuffs in the lower Miocene, with a possibility of their extending into the middle Miocene. Layers of one of the basaltic facies of the diabase are found in such relation to the tuff as would indicate the contemporaneity of the two. This theory is strengthened by the fact that this characteristic basaltic facies, with the exception of the outflow near Stanford University, has been found so far only within the Langley Hill-Mindego Hill igneous area, to which the tuff is confined. The true diabase is later than the basaltic facies and associated tuffs, as it is intrusive both in the tuffs and in shale beds overlying them. The Purisima formation overlies unconformably both the tuffs and their overlying shale beds. (See Fig. 3.)

The tuffs vary in composition from solid masses of basaltic diabase fragments to almost pure limestone, sandstone and shale, depending on the conditions under which they were formed. It is a significant fact that the fragments of igneous rock in the tuff are, in all cases so far noticed, composed of the basaltic facies of the diabase. This is to be expected, as the extrusive forms of the rock would naturally be finer grained than the intrusive ones. The material in which the fragments of igneous rock are imbedded is generally more or less limy, thus showing that the fragments were de-

posited in water at least deep enough to be the habitat of lime-forming organisms. The theory that most of the tuffs were deposited in comparatively deep water is strengthened by the fact that the fragments in most of the beds are angular, which would not be the case had the tuffs been deposited near enough the surface of the water to be affected by the action of the waves.

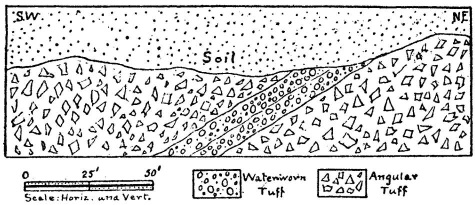


Fig. 10. Section exposed along the Searsville-La Honda road one-fourth mile north of La Honda, showing water-worn tuff interbedded between massive angular tuff.

Fig. 10 shows a section which is exposed along the Searsville-La Honda road a quarter of a mile north of La Honda. Interbedded with the angular tuff is a layer of water-worn tuff about twenty feet thick. The angular tuff appears to have been deposited in the sea in successive layers until it reached near enough the surface of the water to be affected by the wearing action of the waves, when the water-worn layer was formed of the fragmental material. After a time a submergence took place and the top of the deposit was again lowered to such a depth as to be unaffected by the waves, or else the volcanic ejectamenta filled up the shallow sea quite above the water level.

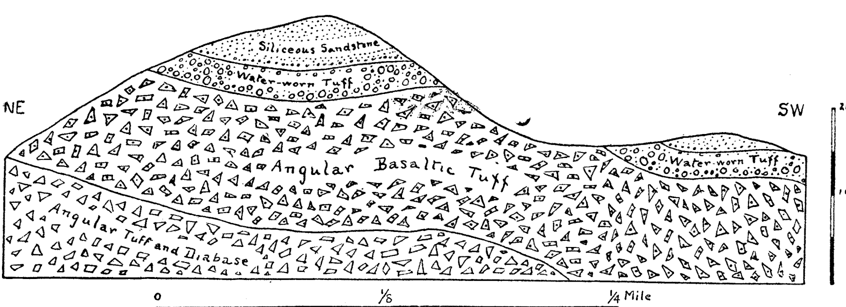


Fig. 11. Northeast-southwest section through the top of Mindego Hill, showing the relations of the different tuffs exposed on it.

Another interesting example of the relation between different facies of the tuff is shown in Fig. 11, which represents a section through the top of Mindego Hill. Here the angular tuff is overlain by a water-worn tuff, which in turn grades by easy stages into a siliceous sandstone. The line of demarkation between the angular and water-worn tuffs is very distinct, the former being dark colored and grading into an almost massive basalt below, while the latter is composed of well-worn fragments of light-colored weathered amygdaloidal basaltic diabase. The water-worn layer grades into a tuff, which is composed of fragments of rock replaced by chalcedony, and then into a fossiliferous sandstone in which some of the fossils and much of the rock have been replaced by chalcedony. Chalcedony and quartz veins and chalcedony-lined cavities are common in the beds above the typical water-worn tuff.

A peculiar tuff, composed of water-worn pebbles of the basaltic diabase imbedded in a fine, brown, ash-like matrix, is exposed on the Searsville-La Honda road just south of the mouth of Langley Creek. Where weathered this tuff so much resembles a true diabase containing pebbles of basalt that at first its origin was quite

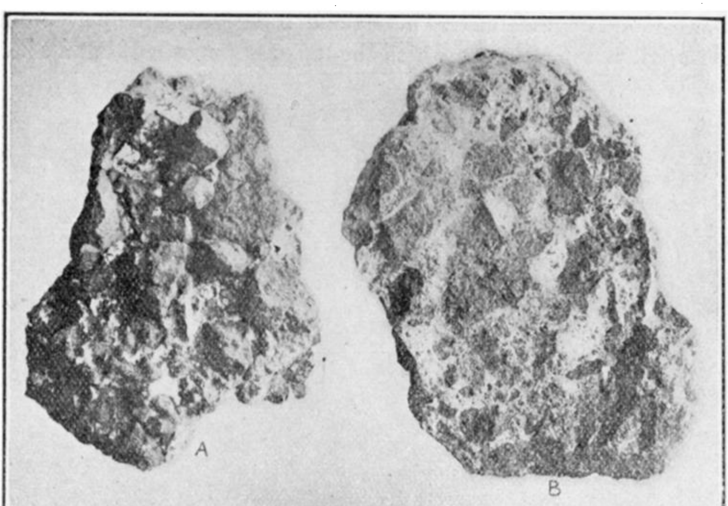


Fig. 12. (*a*) Showing weathered and (*b*) fractured surface of the typical limy tuff from the hill north of the Langley ranch house. Reduced one-half. Photograph by Ralph Arnold.

puzzling. The layer is interbedded between shale layers and at first was thought to be intrusive in the shale, but a later examination showed its true relation to the shales and its clastic origin.

The typical tuff is found in thick beds all along the southwestern and part of the northeastern side of the Langley Hill-Mindego Hill ingneous area. Fig. 12*a* is a photograph of a hand-specimen showing a weathered surface of the tuff, while 12*b* shows a freshly fractured surface. The fragments composing the tuff are of dark-colored basaltic diabase, angular in outline and varying in size from the smallest grains to large masses weighing several hundred pounds. The slides of these fragments show them to be badly weathered, a few feldspars, a little augite and the magnetite and ilmenite being the only recognizable original constituents. The fragments are imbedded in a limy matrix, varying in composition from pure lime to a limy shale. Spheroidal weathering of the tuffs was noticed in one or two instances. Small organic remains are often found associated with the rock fragments in some of the more limy tuffs. Much, and sometimes all, of the lime occurs in a secondary form, as veins of calcite surrounding the fragments or cutting through the tuff. Pure calcite crystals weighing several ounces are sometimes found in the tuff. This calcite is derived principally from the original lime beds in which the tuff was deposited, but a little

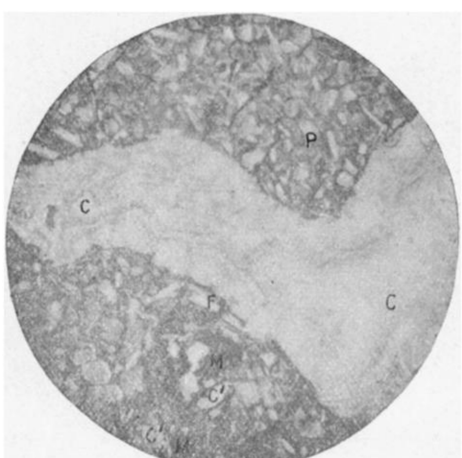


Fig. 13. Thin section of diabase tuff, showing secondary calcite vein, (C); patches of secondary calcite, (C′); feldspar, (F); magnetite, (M). × 20. Photograph by Ralph Arnold.

of it may come from a weathering of the feldspars of the basaltic fragments. Patches of isolated calcite are also found in most of the slides of both the basaltic and diabasic rocks. Fig. 13 shows a slide of diabase tuff from the hill east of the Langley ranch house. A secondary calcite vein (C) and small isolated patches of calcite (C′) are seen in this slide. Veins of chalcedony and limestone dikes or intrusions are also common in the tuffs.

Limestone Dikes.

One of the most interesting phenomena met with in a study of the Langley Hill-Mindego Hill igneous area is the occurrence of limestone dikes or intrusions in the tuff beds. The best exposures of these dikes are found in the ridge to the north of the Langley ranch house. Figs. 14 and 15 show transverse and longitudinal sections of this ridge, respectively. Similar dikes occur in the tuff

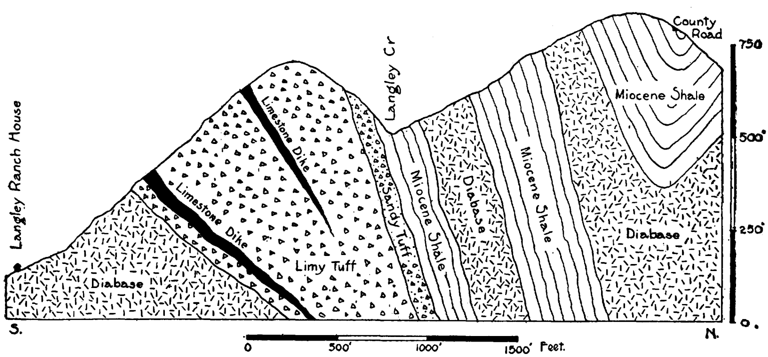


Fig. 14. North-south section through the Langley ranch, showing the stratigraphic relations of the tuffs which contain the limestone dikes.

which makes up the ridge running southeast from the top of Langley Hill, and also in the tuff exposed along the Searsville-La Honda road north of La Honda.

Fig. 15 shows the relative position and size of the principal dikes exposed in the ridge north of the Langley ranch house. These dikes are composed of a more or less pure limestone, in which are generally imbedded fragments of the tuff of varying sizes. The clastic origin of these dikes is shown by their gross structure, their petrographical character and the occurrence of organic remains in nearly all of them. The dikes vary in width from a fraction of an

inch to over thirty feet, and from a few inches to at least one hun-

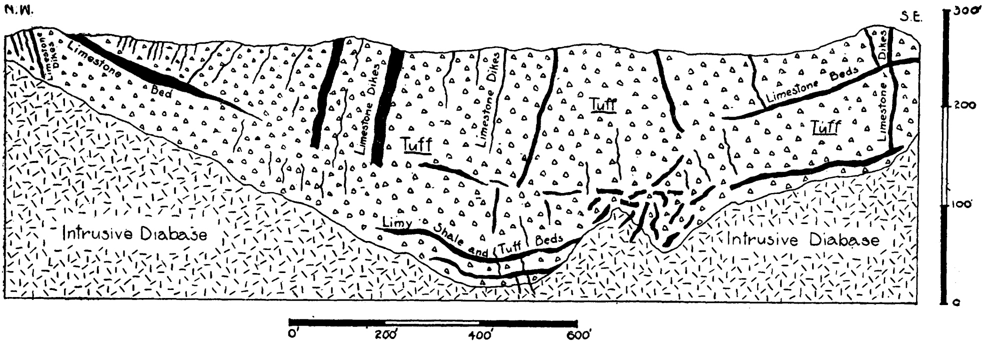


Fig. 15. Northwest-southeast vertical section exposed on ridge north of the Langley ranch house, showing limestone layers interbedded with, and limestone dikes intrusive in, the diabase tuff.

dred and fifty feet in length. Some of them show a kind of flow structure; and a few of them show two systems of joint planes at right angles to each other and both perpendicular to the surfaces

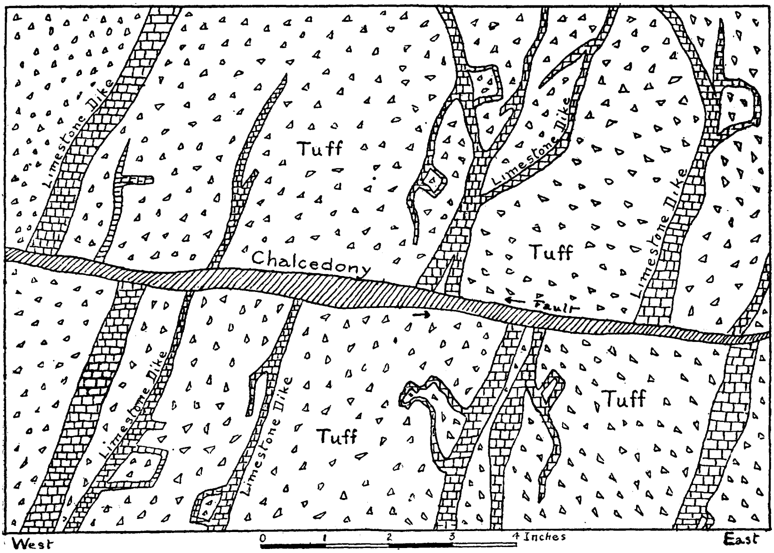


Fig 16. Vertical section showing detail of tuff containing limestone dikes, found on the ridge north of the Langley ranch house. Taken from sketch made in the field.

of the dikes. The surfaces of the dikes are quite irregular, giving a more or less wavy line in section, but the planes of contact of most of the dikes are approximately perpendicular to the bedding planes of the tuff and interbedded limy layers. Some of the dikes extend into the diabase which has intruded the tuff beds. Chalcedony, quartz and calcite form veins and fill cavities all through the tuff, limy tuff beds and the limestone dikes. The minerals deposited from solution are of later origin than the limestone dikes. Fig. 16 shows in detail a small section of the tuff exposed on the side hill north of the Langley house. The chalcedony was deposited along a fault line developed after the intrusion of the limestone into the tuff. Fig. 17 is a photograph taken on the Searsville-La Honda road a quarter of a mile north of La Honda, and shows the tuff cut by limestone dikes and calcite veins.

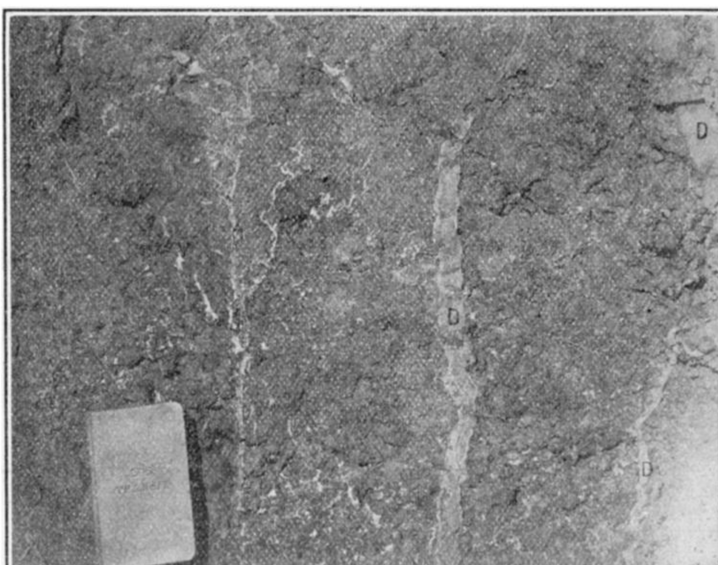


Fig 17. Vertical section along the Searsville-La Honda road one fourth mile north of La Honda, showing limestone dikes (D) and secondary calcite veins (V) in the diabase tuff. Photograph by Ralph Arnold.

The origin of the limestone dikes is easily accounted for when the relations of the containing and associated terranes is consid-

ered. The series of beds in which the dikes occur north of the Langley house have an upward sequence of sandstone, tuff, limy shales, and then alternating thick beds of tuff, comparatively thin beds of limestone and limy tuff, the whole capped by sandy tuff, above which are shale and sandstone beds (see Fig. 14.) Soon after the deposition of this series, and before the tuffs and limestones had become very coherent, diabase was intruded between the lower sandstone layer and the overlying tuffs. The intruded bed fractured the tuff along lines approximately perpendicular to the bedding planes of the series, and the unconsolidated ooze and limy tuff of the interbedded layers flowed into the fissures, thus forming the dikes.

The Diabase.

Studied in the field the diabase presents two facies. One will be termed the diabasic, the other the basaltic. The distinction is made purely on the physical appearance of the two. No great chemical difference exists, but the crystallization, color, texture and manner of weathering are so radically different that, while no differentiation is attempted on the map, a distinction is necessary in describing the rocks microscopically. Secondary dikes of small proportions were found in the diabasic type, and will be briefly described under that head.

The diabasic facies.—The diabasic type seems to be confined to the masses which make the north and east boundaries of the area between the south fork of Tunitas Creek on the north and Langley Hill on the south. In all cases it lies along the crest of the range, making the highest peaks and giving them a peculiar rounded outline that is readily distinguishable at a distance. The rock is well exposed near the summit of the ridge, on the road which crosses the range two and one-half miles south of Sierra Morena. Here the course of the dike is plainly marked by the large rounded boulders on the hillsides. The rocks weather in such a way here as to give particular prominence to the feldspars, thus giving the mass the appearance of a gabbro. The soil derived from its disintegration closely resembles granitic soil. It is made up of granular particles with a slight reddish cast, and varying in size from a diameter of one quarter to one-sixteenth of an inch.

Macroscopically the rock is a medium grained, light gray, crystalline aggregate, in which three components are very readily dis-

tinguishable. One, augite, is present in dark patches intruded by the others, and showing distinct glistening cleavages. Magnetite can be detected in large flat plates and smaller grains, dark and lustrous. Separated with a knife-blade, small portions can be picked up readily with a magnet. The most evident component is the feldspar. It occurs in long white rod-like crystals sometimes as much as two inches in length, giving a reticulated appearance to the mass; it is banded and contains inclusions of magnetite and augite. Fig. 18*b* is a photograph of the typical diabasic facies, being specimen No. 24, the analysis of which is given as I in a following paragraph.

Fresh specimens showing but slight kaolinization are readily obtained. Occasionally a crystal is seen to contain a few clear, glassy spots quite easily distinguishable with a hand lens. They are probably analcite.

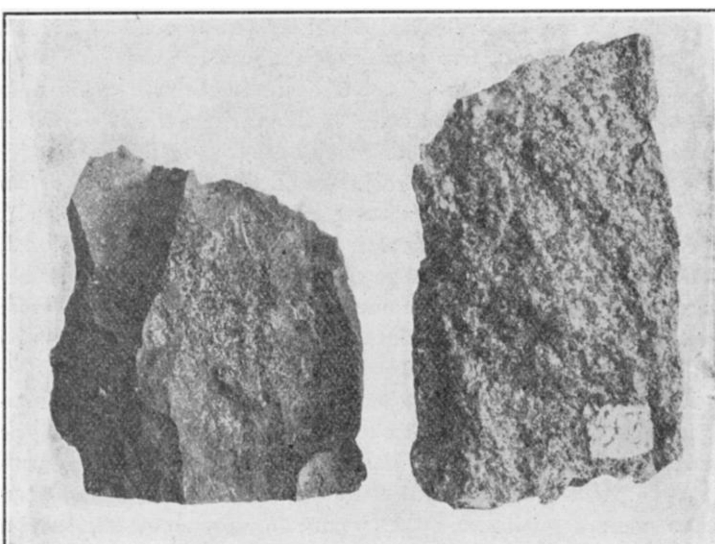


Fig. 18. (*a*) Showing the basaltic (specimen 38) and (*b*) true diabasic (specimen 24) facies of the diabase. Reduced one-half. Photograph by Ralph Arnold.

On the stage road from Redwood City to La Honda, at a point on the west side of the summit, about one-half mile from the Summit

House, the road cuts across the contact of the diabase with the lower Miocene sediments in a small canyon, so that a good cross section is exposed (see Fig. 2). The sediments here dip at an angle of sixty degrees south, twenty degrees west, and the diabase, which is of the coarse variety and rather badly weathered, follows the bedding planes. Within the diabase, running exactly parallel to the contact and dipping with the sediments, are a number of coarsely crystalline secondary dikes, varying in width from one inch to six inches and standing out hard and fresh in the darker decomposed diabase. Figure 2 is a photograph of this dike. The secondary dikes may be seen to the left of the man in the figure.

Macroscopically this rock is medium grained, light colored and with a rather mottled appearance, due to the uneven distribution of the more basic constituents. Augite, plagioclase and magnetite are the chief components. The augites are large and tend to segregate in spots, often with a poikilitic structure; the feldspars being included in the augites and giving a mottled appearance to the rock. The feldspars are long and narrow, somewhat kaolinized and show banding. Clear patches of analcite are frequently included in them. Magnetite is very plentiful in long irregular blades which stand out prominently and often reach a length of half an inch.

A few small cavities in the rocks are filled with a mass of rather flexible, fine, acicular crystals matted together indiscriminately. The crystals are usually light colored, although a few are discolored, evidently by weathering products. Such small amounts were obtained that it was impossible to determine them accurately. Before the blowpipe they are infusible and they are not acted upon by acids.

The basaltic facies.—It is thought best to treat all the fine-grained dark varieties which make up the remaining portion of the area under the head of basaltic facies. These in turn could be readily separated into at least two general types, differing in the coarseness of their crystallization and weathering products, but such a classification would be tedious and will not be attempted. It is necessary to state, however, that those portions of the area which are made up of smaller dikes are almost universally of a coarser texture than the larger masses and exhibit spheroidal weathering in a very striking way. Figure 19 illustrates a typical example of the spheroidal weathering of the medium grained diabase. The basaltic facies differ from the diabasic facies in that they are dark, show-

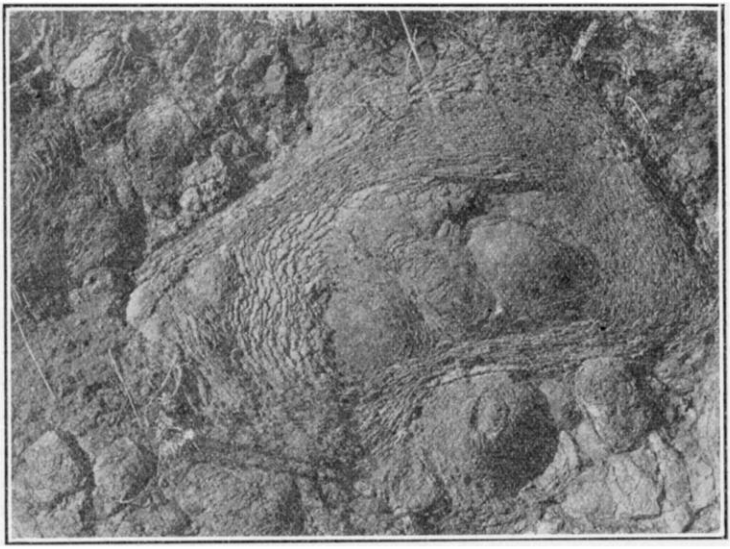


Fig. 19. Spheroidal weathering of the diabase exposed beside the Page Mill road, one-half mile east of the summit. $\times \frac{1}{10}$. Photo. by R. Arnold.

ing the white feldspars but indistinctly, the predominating crystals being augites and olivines. The finer grained varieties make up the larger masses, such as the tuffs and some of the dikes of the Langley Hill-Mindego Hill igneous area, and are often amygdaloidal, weathering into a compact adobe soil. Amygdaloidal cavities of great size are frequently encountered. One cavity filled with quartz measured four inches along its greatest diameter. Calcite, chalcedony and serpentine fill the cavities in many instances, and on Bogess and Harrington Creeks diabase in place was found with its vesicles filled with petroleum. Perhaps the most interesting occurrence is the presence in many places of nests of glassy analcite crystals, filling the amygdaloidal cavities and joints and seams in the rock. Almost perfect icositetrahedrols were obtained. Qualitative tests showed the presence of Al, Na and SiO_2. The mineral is fusible before the blowpipe and soluble in hydrochloric acid, yielding no jelly, however; in this particular agreeing with the observation made by Lawson and Palache[1] on

[1] "The Berkeley Hills," *Bull. Dept. Geol. Univ. Cal.*, Vol. II, p. 418, Berkeley, 1902.

analcite from the andesites in the Berkeley Hills. At several points in the area small irregular aggregates, varying in size from one-tenth to one-half of an inch in diameter, made up of fan-shaped growths of slightly clouded, white crystals, were found in the weathered diabase. When tested before the blowpipe these crystals were found to be natrolite, and a thin section cut from one of the small bodies showed the angular centre area between the natrolite crystals to be filled with analcite (see Fig. 25). Calcite veins of considerable size were found in the mass in some places.

Macroscopically the rock is fine grained and dark. Augite and olivine crystal are readily detected in most specimens, sometimes in crystals large enough to be porphyritic. Plagioclase feldspar and magnetite are also present, and pyrite has been found in a few places. The augite is dark and lustrous and usually quite fresh. The olivine, however, is generally somewhat weathered to serpentine, which often fills the crystal cavity completely and gives the rock a greenish tint. Another weathering product of the olivine was found quite plentifully in thin scales of light brown color. Chemical tests showed the presence of Na, Ca, Fe and Mg. The mineral is hydrous and infusible. Treated with hydrochloric acid, it becomes lighter in color and gives up its iron. These, together with its optical properties, which will be mentioned, make it possible that it is the mineral described by Lawson[1] as iddingsite. The feldspars in this facies are almost universally microlitic. An occasional phenocryst is seen. Magnetite is present in small grains, barely visible to the unaided eye. The basaltic facies usually has a very distinct, coarse, conchoidal fracture. Figure 18*a* is a photograph of specimen No. 38, a piece of the typical basaltic facies, the analysis of which is given as II on a following page.

MICROSCOPIC PETROGRAPHY.

The petrographic discussion contained herein is based upon the study of about one hundred and thirty slides, cut from the rocks collected over the diabase area and examined under the microscope. In thin section the eruptive presents two facies. Both are holocrystalline and contain about the same minerals, but the one presents a rather granular structure under the microscope, just as it does in the hand specimen; the other a finely crystalline, aphanitic

[1] "The Geology of Carmelo Bay," *Bull. Dept. Geol. Univ. Cal.*, Vol. I, p. 31.

structure with smaller individuals, yet of nearly the same chemical composition. While no separation of the two has been attempted in mapping in the field, they will be treated under separate heads in dealing with their microscopic character. In describing their field relations the first has been called the diabasic, the latter the basaltic facies. It is not intended that these terms shall be used to designate two distinct series of rocks, but rather in the sense of a convenient classification of two facies of the same magma.

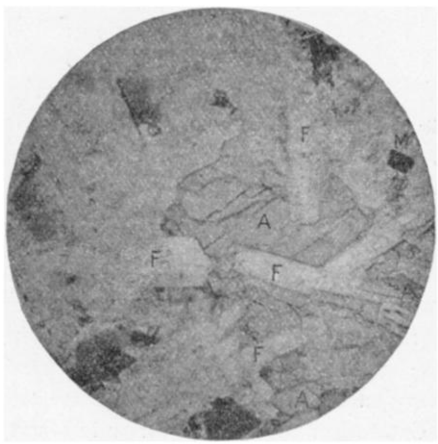


Fig. 20. Thin section of the diabase facies (specimen 24), showing the typical diabase structure. (A), augite; (F), feldspar; (M), magnetite. × 20. Photograph by Ralph Arnold.

The Diabasic Facies.

Considering the general tendency of the eruptive to disintegrate, the diabasic type is usually remarkably fresh and clear in thin sections. The slides show the following principal constituents, given in the order of their crystallization: magnetite, ilmenite, apatite, olivine, feldspar, augite and analcite. The last is never present as an original constituent, so far as could be determined, but is certainly in many cases, and probably in all cases, a secondary product. Of the secondary minerals, serpentine, chlorite, iron ores, calcite and natrolite have been noted.

Plagioclase.—The feldspar is generally present in the diabasic facies in rather stout, lath-shaped forms with an average length of two millimeters, twinned according to the Albite and Carlsbad laws

Fig. 21. Twinned crystal of labradorite, showing cleavage. × 60.

(see Fig. 21). Of the two, the Albite twinning predominates and is usually polysynthetic, and occasionally combined with the Pericline. Crystals cut parallel to the composition plane and showing tabular forms are not infrequent, and in many cases show zonal structure and wavy extinction, indicating a centre more basic than the periphery. Extinction angles were carefully taken and indicate plagioclases of about the order of labradorite with a formula of mixture about Ab_3An_4.

Decomposition of the feldspars has gone on to a great extent in portions of the mass. Comparatively fresh sections are obtainable, however, in places. Kaolinization is very common in all sections. The most characteristic alteration, however, seems to be that which results in the formation of analcite within the feldspar. Nor does it seem that any one law of decomposition applies to all the cases seen. In one instance a mere patch of an isotropic, clear glassy mineral is found in the centre of a plagioclase. In another the crystal form of the feldspar appears to be filled with the product, except, perhaps, a small fresh patch of the original mineral left in the centre, in just such a position as the analcite held in the first case cited. Occasionally the whole crystal is replaced by the analcite. In the slides examined there seems to be much evidence that the analcite is an alteration product (in these instances) of the feldspars themselves. The problem of the percentage of soda required for the

formation of analcite will be discussed under the head of "Chemical Characters."

Lenses of high powers reveal the presence in the feldspars of many dust-like particles, the nature of which is unknown. Usually they are without definite arrangement. Inclusions of gas bubbles, patches of augite, magnetite, and also serpentine and chlorite are noted.

Augite.—Augite is very plentiful in the diabasic facies of the rock, and is usually allotriomorphic with respect to the feldspars. It is of a pale brown color with a tinge of red, probably due to a small percentage of titanium—a supposition which the rock analysis appears to verify. Its pleochroism is faint, changing the shade and not the color. Extinction angles as high as 53° were noted, and zoned crystals with undulatory extinction were occasionally seen. Twinning is not uncommon. Cleavage cracks are very distinct, and the intersecting cleavage lines parallel to the prism of 87° 6′ are frequently observed. The augite is remarkably fresh and clear in this rock, having withstood the effects of weathering better than the feldspars. Smaller crystals of augite, occasionally included in the larger phenocrysts, are often almost entirely decomposed into what appears to be a yellowish-brown chlorite, the coloration being due to the iron ores present. Frequent irregular patches of gas and fluid inclusions occur in the phenocrysts, sometimes long and rope-like, and often clustered around smaller included grains of augite. Irregular inclusions of feldspar are often found and are generally much kaolinized. Magnetite and its decomposition products are also present in the phenocrysts.

Olivine.—Olivine is not abundant in the slides of the diabasic facies. It would have been possible, however, to so choose the sections as to show considerable of this mineral, as its occurrence seems to be in occasional local patches and segregations. It is present, however, in very small quantity in the typical slides, usually in minute clear patches, making up the centre of a mass of brownish decomposition material, badly discolored by iron and showing no characteristic optical properties. Its crystal form, where disintegration is complete, suggests its origin from olivine. In rare instances, too, this secondary decomposition mass assumes a fibrous structure, strong pleochroism and strong double refraction with bright red and green polarization colors, suggesting iddingsite.[1]

[1] "The Berkeley Hills," by A. C. Lawson and Chas. Palache, *Bull. Dept Geol. Univ. Cal.*, Vol. II, No. 12, p. 430, Berkeley, 1902.

Other Minerals.—Magnetite and some ilmenite are present in the diabase as grains and irregular masses. Grouping is occasionally seen, but for the most part both of these minerals are scattered through the mass without definite position.

Apatite is sparingly present in its usual characteristic clear, long, slender prisms, included by the other constituents.

Of the secondary products analcite is by far the most important. It occurs chiefly in the feldspars in the diabasic facies. In no instance could it be shown that it is other than a secondary product, nor does it indicate an origin other than of an alteration product of the feldspars. Treated with hydrochloric acid it is soluble, but forms no jelly.

Fig. 22. Section of secondary dike. (A), analcite; (P), augite; (F), feldspar. × 30.

The Secondary Dikes.—In thin sections the rocks of the secondary dikes contain apatite, magnetite, augite, sphene, feldspar, pyrite, analcite and natrolites (see Fig. 22). The sections are particularly clear and fresh.

The feldspars are plagioclases with the composition of labradorite. They are broadly lath-shaped and show Albite twinning. Wavy extinction with a basic interior and more acid periphery is common

Kaolinization is somewhat advanced; dust-like inclusions, together with augite and magnetite, are frequent.

The augites are of the pale purplish-brown variety with slight pleochroism. They make up an unusually small percentage of the rock, however. Basal sections show wavy extinction. Both idiomorphic and allotriomorphic crystals are present. Cleavage is distinct and relief high. Inclusions of feldspar and magnetite are numerous and decomposition very slight.

Magnetite is present in unusual quantities and in very striking, long, slender rods, as well as in its common tabular forms. A few crystals of pyrite were noted, also a wedge-shaped crystal of sphene.

Analcite and natrolite are present in these sections in greater quantity than in those of any other portion of the mass.

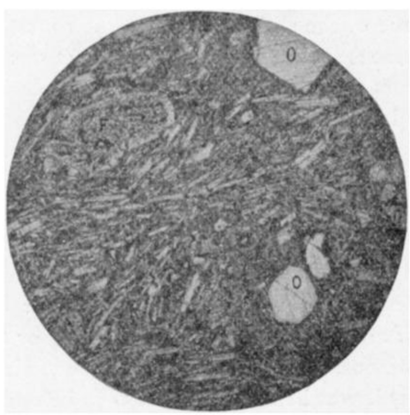


Fig. 23. Section of the basaltic facies (specimen 38), showing basaltic and flow structure. (O), olivine; (O′), olivine weathering to iddingsite; (F), feldspar crystal with etched edges; (A), augite. × 20. Photograph by Ralph Arnold.

The Basaltic Facies.

In thin section the basaltic facies of the igneous mass presents a more difficult problem than the diabasic type, because it is universally more weathered. The typical section shows a few phenocrysts of olivine and augite in a fine-grained ground mass of lath-shaped feldspars, microscopic augites and olivines, ilmenite, magnetite, and the secondary products—calcite, serpentine, chlorite, iddingsite, iron oxides, natrolite and analcite.

Feldspar.—The feldspars are in two general forms—typical lath-shaped crystals and broader tabular plates with wavy extinction or zonal structure and, usually, an abundance of inclusions. The lath-shaped crystals predominate. As far as it was possible to determine them, both seem to be of the order of labradorite and exhibit the same extinction angles that were characteristic of the plagioclases of the diabasic type. Individual crystals are seldom over one millimetre in length. Twinning is usually polysynthetic according to the Albite law, although Carlsbad twins are frequently noted. Flow structure is often beautifully shown by the arrangements of the lath-shaped microlites in regular courses between the larger crystals of augite or olivine (see Fig. 23). Not infrequently the ophitic structure of the typical diabase is seen, the feldspars radiating, in all cases noted, around the larger crystals of olivine. This is particularly true of the slides cut from the rocks of the narrow dikes. In numerous cases, especially in sections showing flow structure, feldspars are bent and broken and displaced. In many slides the ground mass is badly decomposed and shows practically no optical phenomena, except such as is shown by the feldspar microlites which, in these sections, are so badly etched along the crystallographic outlines that they present rough, saw-like edges (see F, Fig. 23). Feldspars differing from the general type are occasionally found in the slides. Slides from one exposure show feldspars which at first glance might be mistaken for orthoclases, so clear and regular are they and free from banding or twinning. Inclusions are numerous, however, and a closer examination of their optical properties leaves little doubt that they belong to the plagioclases. There is an unusual amount of analcite in these slides, which suggests very strongly that the feldspars may contain a larger percentage of soda. Again some sections show feldspars, the order of whose interference colors borders closely on nepheline, and one slide shows a number of crystals whose optical properties would tend to class them as melelites. In view of these resemblances, tests were made upon the thin sections to determine physically whether the optical properties were true indicators. The results, however, left no doubt that the crystals were simply feldspar. Crystals were also found in these slides, portions of which gave the normal optical phenomena of the feldspars common to the rock. Low order interference colors are frequently met with in the more weathered slides, but in no case could nepheline be positively detected.

The matter of the presence or absence of the nepheline was made the object of particularly careful search, as its presence, if established, would materially assist in accounting for the soda necessary to the formation of analcite, as has been observed by Fairbanks in dealing with a very similar rock in San Luis Obispo County.[1] As shown above, however, it is very doubtful whether any nepheline occurs in either facies of the diabase of the area here under discussion.

Pyroxene.—The pyroxenic constituent is usually augite, but enstatite is occasionally noted. The augite occurs, in general, in two ages—a more or less porphyritic series which are occasionally idiomorphic and frequently absent entirely in the slides, and a series of small allotriomorphic grains filling the interstices between the feldspars and olivines of the ground mass. Augites of this latter type are seldom over five-hundredths of one millimetre in diameter, and seem to be identical in composition and optical phenomena with the porphyritic type. No grouping of either type could be detected, the only instance of a perceptible order of arrangement being found in the slides from one small area on Harrington Creek, where porphyritic augites with distinct micropoikilitic structure were observed. The included crystals were particularly fresh plagioclases, which made up about fifty per cent. of the cross section of the pyroxene host. The phenocrysts seldom attained a large size in this facies and were usually broken by mechanical strains or rounded and etched by chemical action, However, elongated crystals with approximately idiomorphic outlines were not uncommon. The augite is of the same pale brown to pinkish tint noted in the diabasic facies. Like it, too, it is but slightly pleochroic, except for some few scattered individuals whose pleochroism is somewhat marked. Polarization colors are very brilliant. Twinning according to the augite law is not uncommon. Only simple twins were noted. Inclusions of glass, gas bubbles and magnetite were noted in the porphyritic crystals.

Enstatite is found in a few instances in irregular plates showing low interference colors. The crystals were in no case large, two-tenths of one millimetre being the greatest diameter measured. The surfaces of the crystals were distinctly pitted, but no distinct

[1] "Analcite Diabase," by H. W. Fairbanks, *Bull. Dept. Geol. Univ. Cal.*, Vol. I, pp. 273–300, Berkeley, 1895.

cleavage was observed. Irregular patches of the enstatite were found included in the feldspars.

On the whole the pyroxenes are remarkably fresh. Many slides show absolutely no decomposition products even where the feldspars are badly weathered. In a few instances slight chloritization was noted, that being practically the only indication of decomposition.

Olivine.—The olivine, like the augite, is present in two generations, porphyritic and microlitic. The porphyritic crystals are usually idiomorphic and are among the oldest segregations of the magma. They are usually much fractured and jointed, and rounded or embayed by the corrosive action of the magma. Usually disintegration has gone on to such an extent that only the crystal form remains, filled with the secondary products. Where the original olivine remains it is clear and colorless, with strong double refraction and high relief. It usually includes much magnetite in small grains, some glass and dust particles.

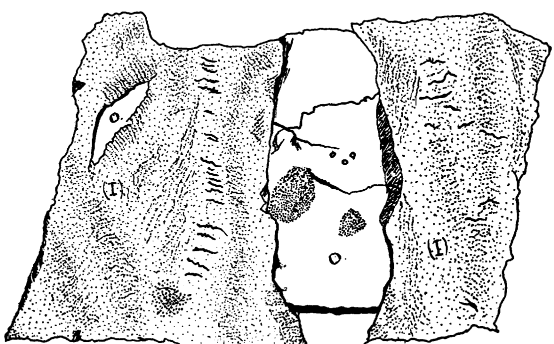


Fig. 24. Phenocryst of olivine (O) weathering to iddingsite (I). × 60.

The most common product of decomposition is serpentine, which frequently shows its fibrous character. Alteration begins along the cracks, gradually working inward from them until the crystal is divided into a number of irregular rounded patches of clear olivine separated by fibrous serpentine, the whole making up the complete form of the original crystal. Perhaps fifty per cent. of the phenocrysts studied were completely replaced in this way, the remainder showing various stages of such decomposition or alteration in like manner to the mineral, which is probably iddingsite (see Fig. 24

and O^1, Fig. 23). It shows high polarization colors and is strongly pleochroic in the green shades, the greatest absorption being parallel to the fibres. It agrees strongly with the mineral described by Iddings[1] from Nevada and afterwards named iddingsite by Lawson. A small amount of chlorite was noted. Calcite is quite abundant in the more weathered portions of the rock. It is usually found filling seams, joints and amygdular cavities.

Fig. 25. Natrolite (N) and analcite (A) between crossed nicols. $\times$ 30.

Analcite.—The most striking product of decomposition is analcite. Its occurrence in the field has been described. In certain areas it is quite plentiful. In thin section it is often found associated with natrolite, fibrous aggregates of which it frequently includes (see Fig. 25). It is isotropic, occasionally showing optical anomalies. It has been observed to occur in five general ways: 1. In irregular patches in the centre of crystals of plagioclase. 2. In a form suggesting a decomposition product of the plagioclases, advancing in irregular lines from the crystal edges inward. 3. Completely filling what seems to have been the rectangular outline of a plagioclase crystal. 4. In irregular patches filling the angular

[1] "Geology of the Eureka District, Nevada," by Arnold Hague, Mon. XX, *U. S. G. S.*, Appendix B, pp. 388–390, Washington, 1892.

spaces between crystals of feldspar. 5. In large irregular patches sometimes two and a half millimetres in diameter, filled with a confusion of microlites of some indeterminable mineral.

CHEMICAL CHARACTERS AND ANALYSES.

The writers are indebted to the United States Geological Survey for the analyses (I and II) of the two typical facies. For the purpose of comparison and discussion there have been added analyses of the analcite from Cuyamas [1] (III), the teschenite diabase (IV), plagioclase feldspar (VI) and analcite (VII) from Point Sal,[2] and a typical analysis of labradorite from Dana (V).[3]

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	50.12	49.60	50.55	49.61	56.0	52.72	54.40
Al_2O_3	18.52	16.56	20.48	19.18	27.5	30.46	23.04
Fe_2O_3	2.47	4.28	2.66	2.12	0.7		
FeO	4.11	4.44	4.02	5.01			
MgO	2.68	5.38	4.24	4.94	0.1		
CaO	8.99	9.22	7.30	10.05	10.1	11.01	0.21
Na_2O	5.22	3.31	8.37	5.62	5.0	3.70	13.33
K_2O	1.46	1.25	2.27	1.04	0.4	0.42	0.19
H_2O	1.64	1.44					
H_2O	3.09	2.58	0.44	Ig 3.55		1.44	8.46
TiO_2	1.33	1.86					
P_2O_5	0.18	0.30		0.27			
So_3	0.08	0.17		tr.			
Cr_2O_3	tr.	0.03					
NiO	none	none					
MnO	tr.	0.08					
BaO	0.02	0.06					
	99.91	100.55	100.33	101.39	99.8	99.75	99.63
Sp. Gr.	2.732	2.825		2.782			

(I) Diabase (typical diabasic facies), from one mile north of Bella Vista ranch houses, San Mateo County, California. Specimen No. 24. E. T. Allen, Analyst. (U. S. Geological Survey.)

(II) Diabase (typical basaltic facies), from Mindego Hill, San

[1] "Analcite Diabase," by H. W. Fairbanks, *Bull. Dept. Geol. Univ. Cal.*, Vol. I, p. 293, Berkeley, 1895.

[2] "The Geology of Point Sal," by H. W. Fairbanks, *Bull. Dept. Geol. Univ. Cal.*, Vol. II, pp. 1–92, Berkeley, 1896.

[3] *System of Mineralogy*, by J. D. Dana. Sixth edition.

Mateo County, California. E. T. Allen, Analyst. (U. S. Geological Survey.)

(III) Analcite diabase from Cuyamas, San Luis Obispo County, California. V. Lenher, Analyst. (Fairbanks.)

(IV) Augite-teschenite from Point Sal. Santa Barbara County, California. (Fairbanks.)

(V) Labradorite, typical analysis, Dana, System of Mineralogy, Sixth Edition, p. 337.

(VI) Feldspar from Augite-teschenite, Point Sal, Santa Barbara County, California. (Fairbanks.)

(VII) Analcite from Augite-teschenite, Point Sal, Santa Barbara County, California. (Fairbanks.)

The close relation between the two facies, as far as chemical composition is concerned, is very evident. A striking similarity exists also between them and the two analyses of very similar rocks from San Luis Obispo County, described by Fairbanks as analcite diabase and augite-teschenite. Hand specimens and a few slides of these latter rocks which were studied for comparison tend to emphasize this similarity, and to make it reasonably certain that the rocks are very closely related in all their properties. In that connection it seems that the evidence gathered by Fairbanks,[1] in dealing with the probable origin of the analcite in rocks which are of this same type, is particularly applicable here. Fairbanks' analyses both show a slightly greater percentage of soda. Optically his feldspars agree with those encountered here. Chemically they are very like the typical labradorite of Dana (V). Nothing new beyond the data given by Dr. Fairbanks in his discussions was discovered in the examination of the rocks herein described. The conclusions reached by that author, however, are but vaguely substantiated. The presence of nepheline, at some time in the history of the diabase, has not been proven. Aside from the fact that analcite is present, and that the soda necessary to permit of its formation could not have come from a concentration of that element from the feldspars alone, to the extent that the entire rock should show a percentage of soda equal to that of labradorite, there is nothing to suggest the presence of nepheline at any time. The presence of the analcite chiefly within the feldspars themselves would point

[1] "Geology of Point Sal," *Bull. Dept. Geol. Univ. Cal.*, Vol. II, p. 30; and "Analcite Diabase," *Bull. Dept. Geol. Univ. Cal.*, Vol. I, p. 293, Berkeley, 1896.

to its origin as a product of their partial disintegration; while its presence filling angular cavities between crystals of feldspar would indicate that it might have replaced whatever mineral originally filled that area, for it is hardly possible to conceive of that area being left vacant after the magma had cooled and crystallized. Yet, were it conceded that nepheline did occupy these areas, it would still be impossible to believe that it could furnish enough soda for the patches included in the feldspars. This problem remains unsolved.

Titanium is present in some quantity, as shown by the analyses of the rocks discussed in this paper. None, however, is listed from those studied by Fairbanks. It is possible that no determination of that element was attempted by him. The presence of such an amount of titanium, however, suggests that the augite, which is of the pinkish variety both in this occurrence and in those described by Fairbanks, carries some titanium. Ilmenite, which is sparingly present, probably accounts for the remainder.

Summary and Conclusion.

Within an area of about three hundred square miles, most of which is shown on the accompanying map, there are exposed about thirty-five square miles of diabase in the form of tuffs, dikes and intrusive sheets. The tuffs are interbedded with lower Miocene strata and overlain by probable middle Miocene shales. The basaltic facies of the diabase is partly contemporaneous with the tuffs and partly of later origin, while the diabase facies is intruded into the tuffs and middle Miocene beds. The igneous rocks under discussion are therefore of lower and middle Miocene ages.

The tuffs are composed of fragments of the basaltic facies, generally angular, but sometimes water-worn. The tuffs are interbedded with limestones, sandstones and shales. Intrusions of limestone derived from the interbedded limy layers have been forced into fissures in the tuff.

Petrographically the diabase is of two general types. One is a light colored, granular rock which is found along the crest of the range north of Langley Hill. The other is a darker, fine grained, basaltic type with occasional phenocrysts of olivine and augite; the latter type makes up the remaining area.

The rock is uniform in its chemical composition, which approxi-

mates that of the typical diabase. The percentages of soda and titanium are large. The former is probably due to the amount of analcite present, and the latter to the character of the augite.

The rocks are closely allied in character and age to those described by Fairbanks from San Luis Obispo and Santa Barbara Counties under the name of augite-teschenite. While analcite is present in considerable quantity and is one of the most interesting features of the rocks, it is also found in basic rocks in several instances on the Pacific Coast, and its presence, taken in connection with other properties of the rock, is not regarded as sufficient to warrant the substitution of the name augite-teschenite for that of diabase. That name has, therefore, not been retained by the writers.

Stated Meeting, February 19, 1904.

President SMITH in the Chair.

An invitation was received from the University of Wisconsin to send a representative to the Jubilee of the University, to be held at Madison, commencing June 5, 1904, and the President was, on motion, directed to appoint a delegate.

The donations to the Library were laid on the table and thanks were ordered for them.

The following papers were read:

"Present Aspects and Future Prospects of Forestry in Pennsylvania," by Prof. Joseph T. Rothrock. Discussed by Prof. Haupt, Mr. Stuart Wood, Mr. Richard Wood, Dr. Marshall and Mr. Goodwin.

"Views of Old Philadelphia," by Mr. Julius F. Sachse. Discussed by Mr. Goodwin, Mr. Stuart Wood, Mr. Harrison and Mr. Richard Wood.

"A Method of Controlling the Floods of the Mississippi River," by Prof. Lewis M. Haupt. (See page 71.)